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Definition of Accurate Reference Pattern for the DTU-ESA VAST12 Antenna

S. Pivnenko[1], O. Breinbjerg[1], S. Burgos[2], M. Sierra-Castañer[2], H. Eriksson[3]

[1]*Dept. of Electrical Engineering, Technical University of Denmark*
Ørsteds Plads, bldg. 348, DK-2800 Kgs. Lyngby, Denmark
sp@elektro.dtu.dk

[2]*Universidad Politécnica de Madrid. E.T.S.I. de Telecomunicación*
Ciudad Universitaria, 28040 Madrid, Spain
sarab@gr.ssr.upm.es

[3]*SAAB Microwave Systems, SE-412 89 Gothenburg, Sweden*
hakan.mg.eriksson@saabgroup.com

Abstract— In this paper, the DTU-ESA 12 GHz Validation Standard (VAST12) Antenna and a dedicated measurement campaign carried out in 2007-2008 for the definition of its accurate reference pattern are first described. Next, a comparison between the results from the three involved measurement facilities is presented. Then, an accurate reference pattern of the VAST12 antenna is formed by averaging the three results taking into account the estimated uncertainties of each result. Finally, the potential use of the reference pattern for benchmarking of antenna measurement facilities is outlined.

I. INTRODUCTION

The DTU-ESA 12 GHz Validation Standard (VAST12) Antenna was designed and manufactured at the Technical University of Denmark in 1992 under a contract from the European Space Research and Technology Center [1]. The VAST12 antenna is shown in Fig. 1. The main purpose of the VAST12 antenna is to facilitate antenna test range intercomparisons for the European Space Agency (ESA).

In 2004 ESA permitted the use of the VAST12 antenna for the European Union network "Antenna Center of Excellence" – ACE [2]. Within the Activity 1.2 of the ACE network, the First Facility Comparison Campaign was carried out with the VAST12 antenna during 2004-2005, which involved several universities and private companies with a total of 9 different measurement facilities. The results of the campaign are documented in the report [3] available from the ACE portal, Virtual Centre of Excellence [4].

An accurate reference pattern of a reference antenna, such as the VAST12 antenna, is clearly desirable, since this pattern allows a benchmarking of antenna test ranges and estimation of their measurement uncertainties. Potentially, it also provides a means to identify and correct errors in the applied measurement procedures by carefully analyzing the results of pattern comparisons supported by knowledge of pattern deviations due to typical errors of the measurement setups.

Three possible approaches for definition of a highly accurate reference pattern and their pros and contras were discussed in [5]. Following the most reliable approach, a dedicated measurement campaign was planned and carried out in 2007-2008 for definition of a highly accurate reference pattern for the VAST12 antenna [5], [6].

In this paper, a comparison between the results from the three participating facilities is presented and the observed differences are analyzed. The accurate reference pattern of the VAST12 antenna is then formed by averaging the three results taking into account the estimated uncertainties of each result. The uncertainty of the reference pattern is also estimated. Finally, the potential use of the reference pattern is outlined.

Fig. 1 The 12 GHz Validation Standard Antenna.

II. THE 12 GHZ VALIDATION STANDARD ANTENNA

The VAST12 antenna is an offset shaped parabolic reflector with circular projected aperture, see Fig 1. The feed is a corrugated horn with a polarizer allowing changing from linear to circular polarization. In order to make the antenna rigid and thermally stable, the support structure is made of carbon-fiber reinforced plastic (CFRP) sandwich, while the mounting flange and reflector suspension points are made of stainless steel. The reflector is made of high density acrylic foam covered in the front and in the back with several layers of CFRP in four directions. The reflecting surface is silver painted with a protective paint on top. The dimensions of the

VAST12 are 842mm x 508mm x 939mm and the weight is about 20 kg. The operating frequency is 12 GHz. A complete description of the design, manufacturing, and testing of the VAST12 antenna is given in [1].

For the purpose of facility comparisons, three coordinate systems (CS) are defined: the optical CS is defined by a mirror cube attached at the top of the reflector, the mechanical CS is defined by the mounting flange and a level placed on the support arm, and the electrical CS is defined by the direction of the maximum co-polar pattern and the orientation for minimum cross-polar pattern in that direction [1].

III. Dedicated Measurement Campaign

A dedicated measurement campaign for definition of an accurate reference pattern of the VAST12 antenna was planned and carried out in 2007-2008. It was decided that each involved facility should carry out a series of measurements with small modifications in the setup aiming at a reduction of the effect of the largest uncertainties. In addition, thorough checks and additional adjustments, if deemed necessary, have been performed in order to ensure the highest accuracy of the results.

The chosen CS for the reference pattern is the mechanical CS, which can be directly implemented in many facilities and thus does not require any additional coordinate transformations. It was agreed that the uncertainty estimates for the obtained patterns should be carried out according to a unified approach developed in the work package 1.2-2 “Standardization of Antenna Measurement Techniques” of the ACE network 2006-2007 [7].

Three facilities participated in this dedicated campaign: the measurements were carried out at the DTU-ESA Facility at the Technical University of Denmark (DTU) in June 2007, at SAAB Microwave Systems (SAAB) in September 2007, and at the Technical University of Madrid (UPM) in January 2008.

The measurements at DTU (spherical near-field facility) consisted of 14 full-sphere near-field acquisitions, which were aimed at estimating and reducing the uncertainties related to:

- Axes intersection and pointing of the mechanical setup
- Amplitude and phase drift and noise
- Receiver non-linearity
- Probe polarization and channel balance
- Multiple reflections between the AUT and probe
- Mounting structure interference

The final result is formed as a complex far-field average of 12 of the available full-sphere data.

The measurements at SAAB (compact range facility) consisted of 21 far-field measurements performed over transverse range of ±1 meter, at two different longitudinal positions differed by $\lambda/4$. All pattern measurements were then also repeated for a roll angle +180° (mirror measurement). The uncertainties were thus reduced related to:

- Wall reflections
- Edge diffraction at the compact range reflector
- Multiple reflections between the AUT and the compact range
- Amplitude and phase drift and noise

The final result is formed as a complex far-field average of all available patterns.

The measurements at UPM (spherical near-field facility) consisted of 18 full-sphere near-field acquisitions, which were aimed at estimating and reducing the uncertainties related to:

- Mechanical uncertainties of the setup
- Chamber reflections
- Mounting structure interference
- Receiver non-linearity
- Multiple reflections between the AUT and probe
- Amplitude and phase drift and noise

The final result is formed as a weighted complex far-field average of 13 selected patterns.

IV. Comparison of the Results

The available three patterns from the participating facilities represent the best achieved results with high accuracy. It is thus very interesting to compare these patterns and observe the agreement. The patterns are available as co-polar and cross-polar cuts in two main planes and two diagonal planes of the mechanical coordinate system. The patterns from the three facilities are shown in Fig. 2.

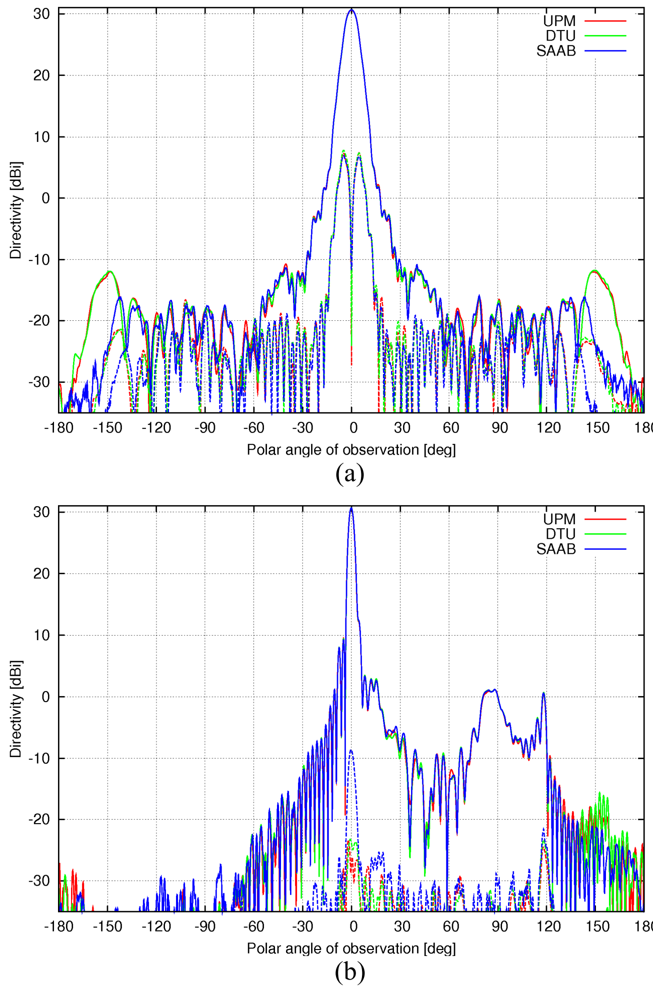


Fig. 2 The measured patterns from the three facilities: (a) $\phi = 0°$ plane and (b) $\phi = 90°$ plane.

It is seen from Fig. 2 that there is an excellent agreement between all three results in the main beam and first sidelobes for the co-polar component. The deviation between the patterns is seen mainly at the low levels, where the influence of noise becomes significant. For the cross-polar component, the agreement is also very good in the main beam region, except for the SAAB result in the θ = 0° direction; this was later found to be caused by high cross-polar level in one of the ports of the compact range feed.

The large scale of Fig. 2 prevents seeing fine details of the difference between the patterns. Fig. 3 shows the logarithmic difference $\Delta_{\log}$ between the co-polar patterns for θ ∈ [–30°, 30°]. The logarithmic difference is defined as follows:

$$\Delta_{\log}(\theta,\phi) = 20\log_{10} f_1(\theta,\phi) - 20\log_{10} f_2(\theta,\phi), \qquad (1)$$

where f_1 and f_2 are the magnitudes of the considered components of the directivity patterns.

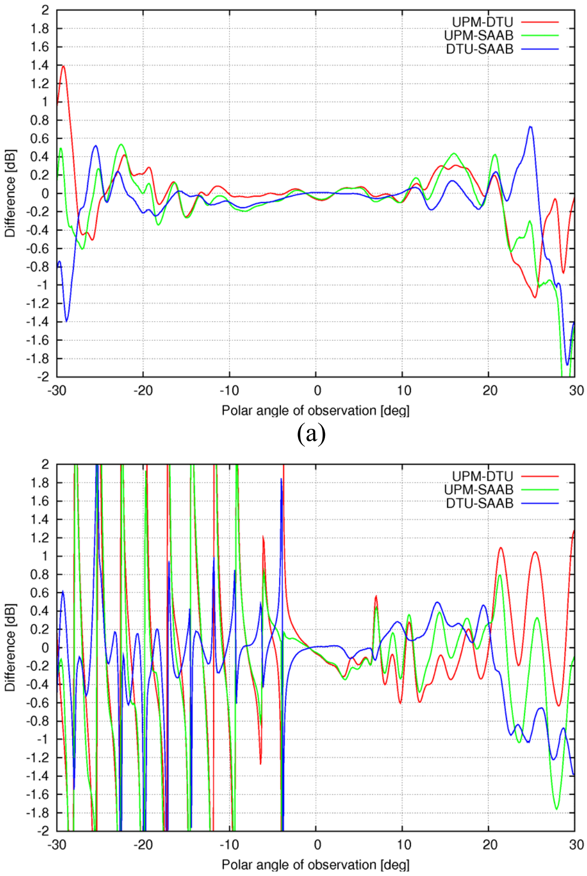


Fig. 3 Logarithmic difference between the co-polar patterns: (a) ϕ = 0° plane and (b) ϕ = 90° plane.

It is seen from Fig. 3 that in the ϕ = 0° plane the difference does not exceed 0.1 dB close to the on-axis direction. In the ϕ = 90° plane the difference is larger due to many sharp nulls between sidelobes. It can also be noted that the difference between DTU and SAAB patterns is generally smaller as compared to the difference of these patterns to the UPM pattern.

V. Reference Pattern Definition

The Reference Pattern (RP) is established by averaging the results from the three facilities with weights inversely proportional to the squares of their estimated uncertainties, according to [5], [8]:

$$20\log_{10} f_R(\theta,\phi) = u_R^2 \sum_{i=1}^{3} \frac{20\log_{10} f_i(\theta,\phi)}{u_i^2} \qquad (2)$$

where f_i represents the magnitude of the considered component of the directivity pattern, u_i^2 designates the square of the standard uncertainty (1σ) for each result, and u_R^2 denotes the square of the standard uncertainty of the RP, which is given by:

$$u_R^2 = 1 \Big/ \sum_{i=1}^{3} \left(\frac{1}{u_i^2} \right) \qquad (3)$$

By establishing the RP in this way, it is ensured that its uncertainty is smaller than the uncertainties of each of the contributions. The standard uncertainties for maximum co-polar directivity estimated by each participating facility are shown in Table 1 together with the calculated standard uncertainty of the RP.

TABLE I
Standard Uncertainty of the Measured Patterns and the RP

	DTU	UPM	SAAB	RP
Standard uncertainty	0.010 dB	0.016 dB	0.006 dB	0.005 dB

VI. Comparisons with the Reference Pattern

The availability of an accurate RP allows a benchmarking of the measurement results obtained at the individual facility. This will be illustrated by using the results of the three participating facilities through comparison of their measured patterns with the RP.

First, the weighted logarithmic difference $\Delta_{w,\log}$ is introduced in order to de-emphasize the large spikes of the logarithmic difference, which are present near the sharp nulls in the patterns, see Fig. 3b.

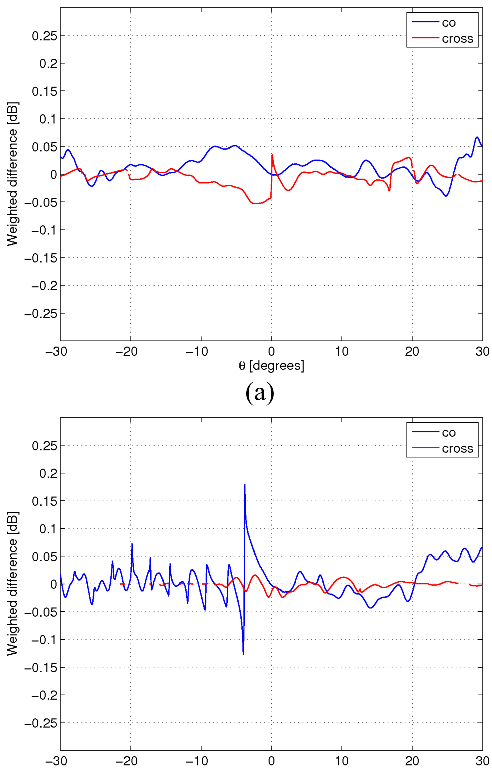
$$\Delta_{w,\log}(\theta,\phi) = W_{\log} \cdot \Delta_{\log}(\theta,\phi) \qquad (4)$$

The weighting function is chosen as follows:

$$W_{\log} = \left(f_R(\theta,\phi) / f_{R,\max} \right)^{\beta} \qquad (5)$$

with $\beta = 0.6$ that results in halving the weight for each 10 dB drop in the RP.

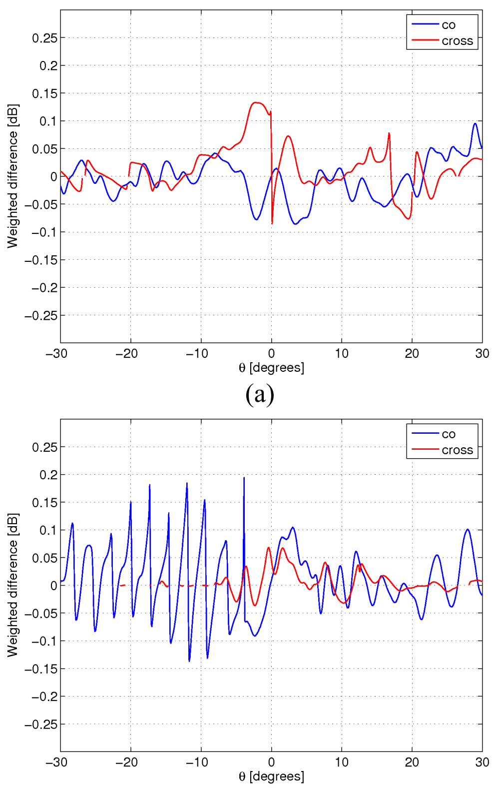
The weighted logarithmic difference between the co-polar patterns for θ ∈ [–30°, 30°] of the results from DTU, UPM and SAAB versus the RP are shown in Figs. 4-6. It is seen from Figs. 4-6 that the comparison of several patterns versus an accurate RP, i.e. in equal conditions, clearly illustrates the quality of the results and highlights their problems such as a slight pointing error in the ϕ = 90° plane for the UPM pattern and high cross-polar level for the SAAB pattern.



(a)

(b)

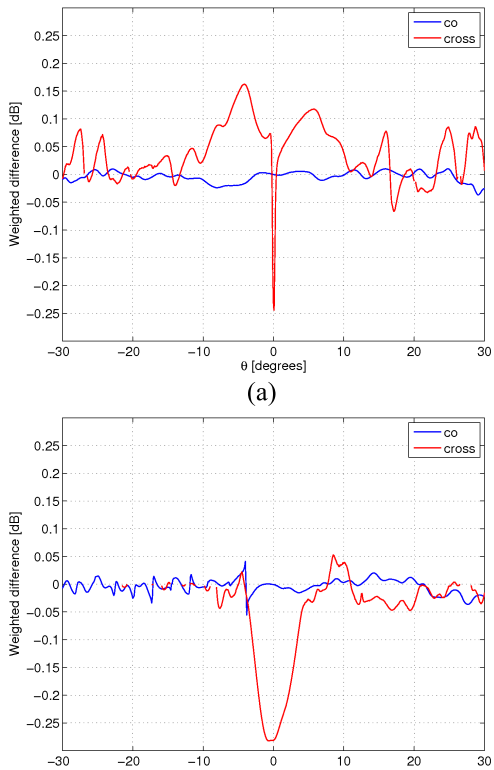
Fig. 4 Weighted logarithmic difference for comparison of DTU vs. RP: (a) $\phi = 0°$ plane and (b) $\phi = 90°$ plane.



(a)

(b)

Fig. 5 Weighted logarithmic difference for comparison of UPM vs. RP: (a) $\phi = 0°$ plane and (b) $\phi = 90°$ plane.



(a)

(b)

Fig. 6 Weighted logarithmic difference for comparison of SAAB vs. RP: (a) $\phi = 0°$ plane and (b) $\phi = 90°$ plane.

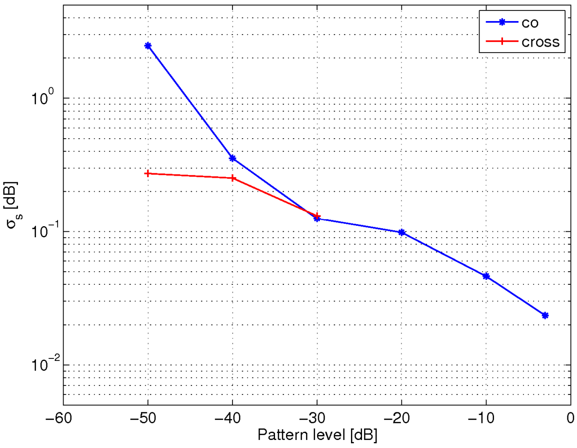
The standard deviation calculated for the weighted logarithmic difference between the co-polar patterns for $\theta \in [-30°, 30°]$ is given in Table 2. These values represent the measurement uncertainty of the results in the considered angular region.

TABLE II
STANDARD DEVIATION OF THE WEIGHTED LOGARITHMIC DIFFERENCE BETWEEN THE CO-POLAR PATTERNS FOR $\theta \in [-30°, 30°]$

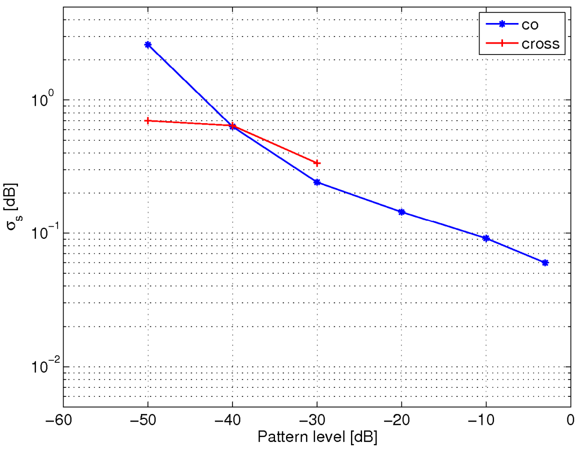
St. Dev.	DTU vs. RP	UPM vs. RP	SAAB vs. RP
co-polar	0.026 dB	0.047 dB	0.011 dB
cross-polar	0.013 dB	0.034 dB	0.077 dB

Another useful comparison can be made by calculating the statistics for the logarithmic difference at different pattern levels, e.g. with a step of 10 dB, considering at each level an interval of ±3 dB. Fig. 7 shows the results of such comparison made by calculating the standard deviation of the logarithmic difference of the results from DTU, UPM and SAAB versus RP. This comparison provides an estimate for the uncertainty of the measured patterns at different pattern levels, which is very often a required characteristic of a measurement facility.

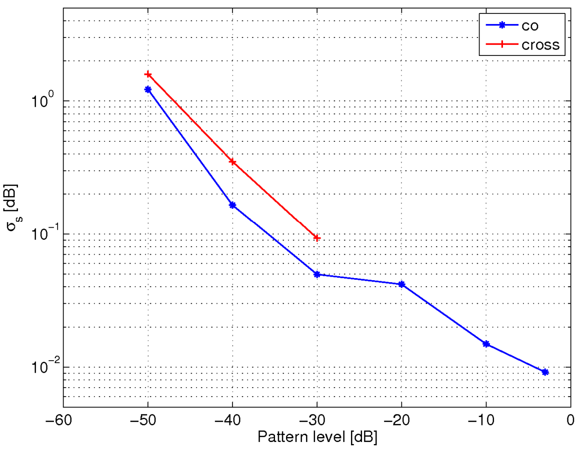
Other statistical parameters, such as mean of the logarithmic difference, cumulative distribution function, or N^{th} percentile can also be calculated either for the whole pattern or at different pattern levels.



(a)



(b)



(c)

Fig. 7 Standard deviation of the logarithmic difference at discrete pattern levels: (a) DTU vs. RP, (b) UPM vs. RP, and (c) SAAB vs. RP.

Clearly, the comparison results shown in this section are not independent, since these were obtained with the RP created from themselves. However, using the RP for comparison with other results will provide reliable estimates of their measurement uncertainties.

VII. Conclusions

An accurate reference pattern was established for the DTU-ESA VAST12 antenna through a dedicated measurement campaign carried out in 2007-2008. The patterns obtained at each of the three participating facilities were averaged taking into account the estimated uncertainties of each result. This ensured that the uncertainty of the reference pattern is minimized.

A comparison of the measurement result from the individual facility versus the accurate reference pattern provides useful information regarding the uncertainty of the results and also allows quantitative evaluation. This can be done by calculating statistics of the difference between patterns either for the whole pattern or at different pattern levels. Appropriate weighting of the difference can be applied in order to emphasize or de-emphasize its particular characteristics depending on the requirements.

The established accurate reference pattern, together with the VAST12 antenna, constitute valuable tools for comparison and benchmarking of the antenna measurement facilities.

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